THE SMALL PROBABILITY OF THE PROCESSES $\mu \rightarrow e + \gamma$, $\mu \rightarrow e + e + e$ *AND NEUTRAL CURRENTS IN WEAK INTERACTIONS*

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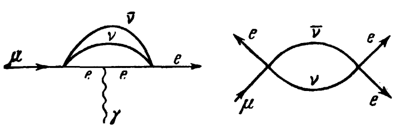
It is pointed out that by introducing neutral currents into the weak interactions, in addition to charged currents, one can obtain a very small probability for the decay processes $\mu \rightarrow e + \gamma$ and $\mu \rightarrow e + e + e$ even in the case that only one neutrino exists in nature.

THERE have been numerous attempts to observe the decay mode $\mu \rightarrow e + \gamma$ during the last fifteen years [1]. Up to the present this decay mode has not been observed, and according to the most precise data [2], its probability is less than $6 \times 10^{-8}\,\alpha$, with a confidence level of 90%, where α is the probability of the mode $\mu \rightarrow e + \nu + \bar{\nu}$. The mode $\mu \rightarrow e + e + e$ has not been observed either [3], and according to the latest data its probability is less than $2.6 \times 10^{-7}\,\alpha$ [4]. The absence of these modes can be connected with the existence of two kinds of neutrinos in nature (a muonic neutrino and an electronic one), possessing different quantum numbers.

The question whether there exist two neutrinos can be uniquely answered by experiment [5], and it seems that an answer to this question will soon be available. In this paper a possibility for explaining the small probability of the above-mentioned decay modes is pointed out, for the case that there exists only one sort of neutrinos. For this it is necessary that in addition to the well known "charged currents" [6], the weak interactions contain also "neutral currents."

Let us consider the case of a direct four-fermion interaction (i.e., without intermediate bosons). Figure 1 shows two typical graphs which could lead to the unobserved processes in which we are interested. Graphs in which baryons participate do not contribute significantly, owing to the formfactors connected with the strong interactions. Decays occur in the second order of perturbation theory.



a b

FIG. 1

They are due to the existence of interactions of the types $(\bar{e}\nu)(\bar{\nu}e)$ and $(\bar{\mu}\nu)(\bar{\nu}\mu)$, which are an essential point in the Feynman-Gell-Mann theory [6]. From the work of Ioffe [7] it follows that the small probabilities for the modes $\mu \rightarrow e + \gamma$ and $\mu \rightarrow e + e + e$ imply surprisingly low values for the cutoff parameter Λ ($\Lambda \lesssim 20$ BeV). If there are no interactions of the $(\bar{e}\nu)(\bar{\nu}e)$ type, the above-mentioned processes can appear in third order in the weak-interaction coupling constant G (cf. for example the graph in Fig. 2, for the mode $\mu \rightarrow e + e + e$).

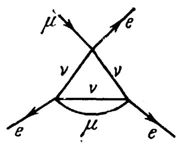


FIG. 2

In this case the cutoff parameter Λ turns out to be considerably larger so that the difficulties connected with the small probabilities of the processes under consideration disappear, at least in part. It is important to note, however, that the simple hypothesis that there are no "diagonal" terms of the type $(\bar{e}\nu)(\bar{\nu}e)$ in the weak-interaction Lagrangian is too unnatural. This hypothesis would destroy the idea of Feynman and Gell-Mann that the interaction between currents is the basis of the four-fermion weak interaction.

There is, however, one possibility of conserving this idea and still forbid the process $\nu + e \rightarrow \nu + e$. This can be achieved on the basis of the hypothesis proposed by Bludman in 1958 [8], the relevance of which to the question of the small probability of the modes $\mu \rightarrow e + \gamma$ and $\mu - e + e + e$ has not been recognized until now (cf. for example [9]).

In Bludman's theory one assumes that the weak interaction Lagrangian consists of two parts: the ordinary part, described by the "charged currents" of the types $e\nu$, $\mu\nu$, μn, pΛ, and a second part, containing the "neutral symmetric currents" $\nu\nu$, ee, $\mu\mu$, nn, pp, $\Lambda\Lambda$.

In this scheme the process $\nu + e \rightarrow \nu + e$ does not exist, since the term $(\bar{e}\nu)(\bar{\nu}e)$ of the " "charged" Lagrangian is compensated by the term $(\bar{e}e)(\bar{\nu}\nu)$ of the "neutral" Lagrangian.

It is important to note that the absence of modes similar to $K \rightarrow \pi + e + e$ is no evidence against this scheme since the currents under consideration are symmetric, i.e., both the currents μe and Λn are eliminated. Note also that the neutral symmetric currents have nothing to do with the $\Delta T = 1/2$ rule for the nonleptonic decay modes of strange particles.

There remains the question whether the introduction of neutral currents does not contradict the existing experimental data. The consequences of the proposed scheme are the following:

1. The existence of several weak processes, e.g. scattering of electrons on protons [10] and on electrons [11] with parity nonconservation. There are no experimental data on this subject and it is very difficult to obtain such data.

2. In first order in the weak-interaction coupling constant the process $\nu + e \rightarrow \nu + e$ must be absent, as already mentioned. No corresponding experiments have been carried out. If it should turn out that the experiments do not show the existence of such a process, this would still not contradict the current-current interaction hypothesis, as is often asserted in the literature.

3. Excited nuclei should emit $\nu\bar{\nu}$ pairs. It is practically impossible to observe this effect in a laboratory, owing to the "competition" of electromagnetic processes. However, it is beyond doubt that this process would have important astrophysical consequences, as it could be responsible for a potent mechanism of energy loss in stars. In this mechanism the $\nu\bar{\nu}$-pair emission by stars is characterized by a process of order G^2, as compared to G^2e^4 in the case of the existence of ν-e scattering [12].

4. In experiments utilizing high-energy neutrinos one should observe scattering of neutrinos by nucleons (and stars formed on composite nuclei) not accompanied by charged leptons. The search for such processes with cross sections of the order of 10^{-38} to 10^{-40} cm^2 per nucleon could give a definite reply to the question of the existence of neutral currents in weak interactions.

In conclusion we note, that should the experiments indicate the existence of only one kind of neutrinos in nature, then the small probability of the processes $\mu \rightarrow e + \gamma$ and $\mu \rightarrow e + e + e$ would be an argument in favor of the existence of symmetric neutral currents in weak interactions.

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